HYDROKINETICS INC.

12975 W. 24th Pl.
Golden, (Applewood) Colorado, 80401
(303) 237-8865
Fax 237-8869

June 14, 2012

Ms. Wendy Cheung
Mr. Chuck Tinsley
U. S. Environmental Protection Agency
Mail Code: 8P-W-GW
1595 Wynkoop Street
Denver, CO 80202-1129

RE: Class I Injection Well DI-1
Permit No. CO-12143-00000
Step Rate Testing

Dear Ms. Cheung and Mr. Tinsley:

INTRODUCTION

As you are aware, on April 3, 2012, we completed a second Step Rate Test (SRT) on our DI-1 injection well. This SRT was conducted to determine whether or not fracturing of the formation is occurring and to obtain flow vs. pressure data for operational purposes.

The first SRT on this well, consisting of four steps, was performed on September 23, 2010 using a wellhead gauge only. The purpose of the additional testing is to perform additional steps (a total of seven) and to obtain additional pressure data using downhole transducers. The ultimate goal is to be able to increase the Maximum Allowable Injection Pressure (MAIP) for the well. We are requesting such an increase in the MAIP because the current MAIP of 1485 psi at the wellhead is inadequate for the District's needs, especially as time passes and the perforations begin to plug and the formation pressures increase.

TESTING PROCEDURES

The formation pressure vs. flow data and graphs from the first SRT are presented again in Appendix A for your convenience.

On April 3, in accordance with EPA's Step Rate Test Procedure and with EPA personnel present, we conducted a seven step test on well DI-1. Each step ran at a constant rate for 30 minutes. Two transducers were lowered into the hole and set near the bottom of the well prior to testing. These

These probes were installed to obtain downhole pressure data during the test. Pressure vs. flow graphs and tables prepared in the field by the contractor Maverick Stimulation Company are attached in Appendix B. The flow rate ranged from 5.2 to 38.9 bbl/min. Even though the pumps were experiencing problems during the seventh step, a reasonable flow rate and pressure was still obtained for this step.

Near the end of the test, the cable holding the transducers separated and the transducers along with about 10,000 feet of wire was lost down the hole. After waiting three days (to obtain falloff pressure data), we spent the next 15 days using a wireline rig and a workover rig with tubing to fish for the transducers. We were able to remove almost all the wire from the well, but were not able to recover the transducers.

ANALYSIS

Even though we were not able to obtain downhole pressure data, we did obtain very valuable flow vs wellhead pressure data for all seven steps. We understand that downhole data are preferred, and we agree, but on page 2 of the Step-Rate Test Procedure the instructions state " If a surface gauge is used, the test pressures must be corrected for the estimated friction loss at each particular flow rate". Based on these instructions, we have corrected the wellhead pressure data for friction loss as described below.

We calculated friction loss using the Darcy Weisbach method widely used in the civil engineering industry for pipeline design. It is generally recognized as the most accurate model for estimating friction head loss in steady pipe flow. Because using the DW method can be fairly tedious, we use an XL spreadsheet prepared by an engineering company called Bright Hub. This spreadsheet can be found on the website Brighthub.com. An explanation of the BrightHub calculations is presented in Appendix C.

The input data used are as follows:

Flow rate = varies
Inside pipe diameter = 4.00 inches
Pipe roughness = 0.0000033 ft. (from pipe manufacturer)
Pipe length = 9052 ft.
Fluid density = 1.936 slugs/cubic foot (assuming temperature is 70 degrees F)
Fluid viscosity = 2.034E-05 lb-sec/sq. foot (see Appendix C for temperature of 70 degrees F).

Note that we incorrectly used the outside pipe diameter of 4.5 inches in our previous report for the first SRT. This error has been corrected as the actual inside diameter of the pipe is 4.00 inches.

The friction loss calculation sheets for each step in both SRT's are presented in Appendix C.

We next plotted the flow vs pressure data for the second SRT and for the two SRT's together (Appendix D). The pressure plotted in the two graphs is the total hydraulic pressure at the center of the perforated zones (9595 feet below ground level) for each step in each test. This pressure was calculated by adding the gauge pressure at the wellhead to the hydrostatic head in the well (4154 psi) and subtracting the friction loss in the tubing.

Both graphs show that pressure increased linearly as flow rate increased. Fracture pressure, which would show itself as a distinct "kink" in the line, was not reached in any of the step tests.

CONCLUSIONS

Based on the analysis above, no fracturing occurs up to and even beyond a wellhead pressure of 5000 psi. We understand that the friction loss corrections are approximate and the actual transducer data would be more accurate, so we are not requesting an MAIP that high. However, we do believe, based on our analysis that an increase in the MAIP to 3200 psi at the wellhead would be reasonable.

If you have any questions, please call.

Sincerely,

Pat OB

Patrick OBrien, PE, CPGS

APPENDIX A. INJECTION RATE VS. FORMATION PRESSURE DATA– FIRST AND SECOND STEP RATE TESTS

DI1 All Perforated Zones, both tests

	A	B	C	D	E	F	G	H	I
1	Injection rate		wellhead	water in	friction loss in		Total pressure at		
2	bbl/min.		Press. psi	hole, psi	in pipe (psi)		center of perfs (psi)		
3							(at 9595 ft)		
4	5.65	1st SRT	830	4154	106	4878			
5	10.2	1st SRT	1170	4154	310	5014			
6	19.9	1st SRT	1980	4154	1048	5086			
7	39.35	1st SRT	4750	4154	3686	5218			
8									
9	Q					V			
10	5.2	2nd SRT	812	4154	92		4874		
11	11.4	2nd SRT	1228	4154	380		5002		
12	17.5	2nd SRT	1719	4154	831		5042		
13	23.8	2nd SRT	2399	4154	1463		5090		
14	29.9	2nd SRT	3268	4154	2225		5197		
15	35.1	2nd SRT	4043	4154	2996		5201		
16	38.9	2nd SRT	4723	4154	3610		5267		
17									
18									
19									
20									
21	Water in hole at								
22	center of								
23	perforations								
24	(9595 feet)								

$$V = Q/A = \frac{\text{bbls/MIN}}{\pi d^2/4} = \frac{\cancel{\text{bbls}}/\text{MIN} \times 5.615\ \text{ft}^3/\cancel{\text{bbl}}}{(\pi\ \cancel{\text{ft}^2})/4}$$

$$= \frac{5.2\ \text{B/MIN} \times 5.615\ \text{ft}^3/\text{B}}{\pi(0.3333\ \text{ft})^2/4} =$$

$$Q = \frac{\text{bbl/MIN} \times 5.615\ \text{ft}^3/\text{bbl} \times}{60\ \text{sec/MIN}} = \frac{5.2 \times 5.615}{60} =$$

APPENDIX B. INJECTION RATE VS. WELLHEAD PRESSURE GRAPHS AND DATA–SECOND STEP RATE TEST

MAVERICK STIMULATION COMPANY, LLC

88 INVERNESS CIRCLE E. G-101
ENGLEWOOD, CO 80112
PH (303) 757-7789 FAX (303) 757-7610

TREATMENT REPORT - PAGE 1

Date: 03-Apr-12

Well Name:	Location:	Customer Rep:	Field Order #
ECCV DI-1	SEC1 - T1S - R66W	SCOTT/FRED	14704

Stage:	Formation:	Treat Via:	Allowable Pressure Tbg	Allowable Pressure Csg	Well Type:
	SEE PROD USED	CASING		5,000	INJECTION

County:	State:	Well Age:	PackerType:	PackerDepth:	Csg Size:
ADAMS	CO	NEW			

Type Of Service: STEP RATE TEST

Customer Name: HYDRO RESOURCES

Address:

Csg Depth:	Tbg Size:	Tbg Depth:	Liner Size:

Liner Depth:	Liner Top:	Liner Bot:	Total Depth:

Open Hole:	Csg Vol:	BHT:	

Perf Depths:		Perfs:	TotalPerfs:
9152	9253	606	1176
9558	9582	144	
9664	9698	204	
9702	9702	6	
10002	10038	216	
		0	
		0	

Remarks: SAFETY MEETING/PRIME UP PSI TESTTO 5000
START RATE TEST AT 5 BPM FOR 30 MIN,11BPM FOR 30 MIN,17BPM FOR30,23BPM FOR 30,29 BPM FOR 30,35 BPM FOR 30,40 BPM FOR 30.
ISIP=831

TIME	INJECTION RATE FLUID	INJECTION RATE N2/CO2	PRESSURE STP	PRESSURE ANNULUS	REMARKS	PROP (lbs)	FOAM/FLD (gls)	FLUID (bbls)
10:08	70.0		0		SAFETY MEETING			
12:43	0.0		19	94	PRIME UP PRESSURE TO 5000 PSI			
12:47	11.1		9	94	FILL CASING			
12:51	5.2		633	9	ST 5 BPM ST PSI 632		6,300	150.0
13:20	5.2		841		END=812PSI			
13:21	11.3		1219		ST 11 BPM AT1228 PSI		13,860	330.0
13:37	6.1		869		PUMP FALT			
13:51	11.4		1228		END 1228 PSI			
13:54	17.5		1766		ST 17 BPM AT1766 PSI		21,420	510.0
14:24	17.5		1719		END 1719 PSI			
14:25	23.7		2409		ST 23 BPM AT 2399 PSI		28,980	690.0
14:53	23.8		2399		END =2399			
14:54	30.0		3268		ST 29 BPM AT 3268 PSI		36,540	870.0
15:23	29.9		3249		END 3268 PSI			
15:25	34.7		4005		ST 35 BPM AT 4024 PSI		44,100	1,050.0
15:52	35.1		4043		LOOSE CONNECTION			
15:54	3.7		4099		END 4040 PSI			
15:58	38.9		4723		ST 39 BPM AT 4820 PSI		27,846	663.0
16:10	39.3		5091		PUMP FALT			
16:16	32.1		3042		COME DOWN GET OFF			
16:18	0.0		822		ISIP=831			

Customer Acknowledgement:

Service Rating:
☐ Satisfactory
☐ Unsatisfactory

Treater: RICK C

PRODUCTS USED
WATER PROVIDED BY CUSTOMER
FORMATION
LYONS,WOLFCAMP,COUNCIL
BLUFF MISSOURIAN

MAVERICK STIMULATION COMPANY, LLC

88 INVERNESS CIRCLE E. G-101
ENGLEWOOD, CO 80112
PH (303) 757-7789 FAX (303) 757-7610

TREATMENT REPORT - PAGE 2

Date: 03-Apr-12

Total:		179,046	4,263.0

Summary

Max Fl. Rate	Avg Fl. Rate	Max Psi	Avg Psi
70.0	23.5	5,186	2,409

Customer Acknowledgement: ____________________

Service Rating:

☐ Satisfactory

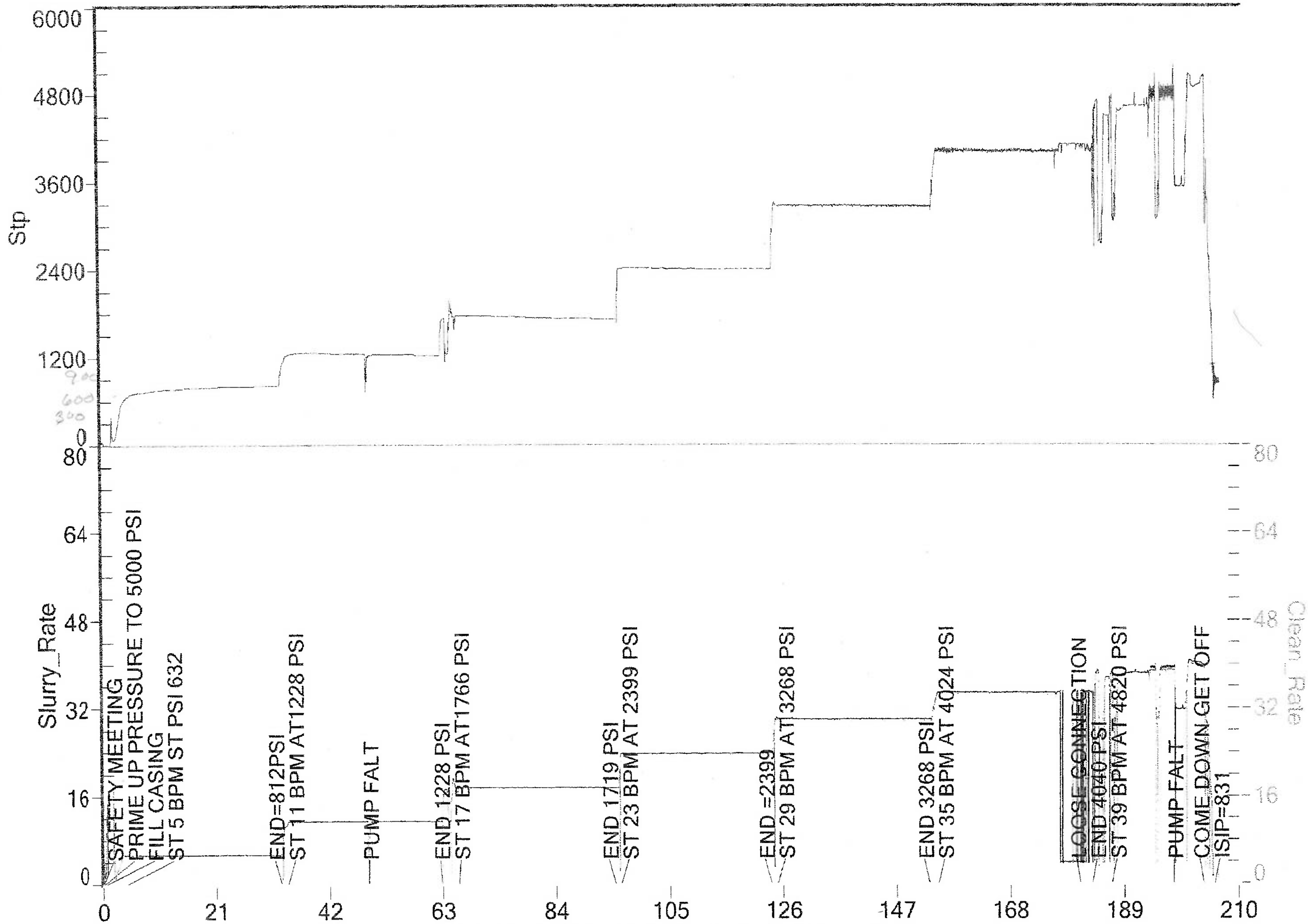
☐ Unsatisfactory

Treater: RICK C

PRODUCTS USED
WATER PROVIDED BY CUSTOMER FORMATION LYONS,WOLFCAMP,COUNCIL BLUFF MISSOURIAN

HYDRO RESOURCES

ECCV DI-1 - LYONS,WOLFCAMP,COUNCILBLUFF,MISSOURIAN - STEP RATE TEST



Job Started On: 04/03/2012 @ 10:08:07 AM

APPENDIX C. DARCY WEISBACH FRICTION LOSS CALCULATIONS

Bright Hub

Pipe Flow/Head Loss/Friction Factor Calculations with Excel Spreadsheet Templates

Written by: Harlan Bengtson • Edited by: Lamar Stonecypher
Updated Oct 11, 2010

Calculation of frictional head loss or pressure drop for pipe flow, using the Darcy Weisbach/ friction factor equation, can be done with downloadable Excel spreadsheet templates given in this article. A template is also given for calculation of pipe diameter needed for given flow rate and head loss.

Pipe Flow/Head Loss Calculations with Excel Spreadsheet Templates

Darcy Weisbach equation/pipe flow calculations like head loss, pressure drop, or required pipe diameter, using Excel spreadsheet templates, are illustrated in this article. The Darcy Weisbach equation [$h_L = f\,(L/D)(V^2/2g)$] gives a relationship among pipe length and diameter (L and D); average velocity in the pipe (V); frictional head loss (h_L); and friction factor (f), where the friction factor is, in general, a function of Reynolds number (Re) and the ratio of pipe roughness to pipe diameter (ε/D). More details about the Darcy Weisbach equation and the variable listed here are available in the article, "Pipe Flow Calculations 3: The Friction Factor and Frictional Head Loss." The friction factor, f, may be determined with the use of a graph or from equations. The graph and equations for f are given in the article just mentioned. Also the equations that will be used for f in these Excel spreadsheet templates are given later in this article.

Calculation of Frictional Head Loss or Pressure Drop

The Excel spreadsheet template shown in the image at the left is set up to calculate the frictional head loss and pressure drop for a specified volumetric flow rate in a pipe of known diameter, length, and roughness.Also, the fluid

density and viscosity need to be known. (**Clicking on the image will enlarge it so it can be read.**) The table at the right gives typical pipe roughness values for use with the Darcy Weisbach equation.

Pipe Material	Absolute Roughness, ε	
	x 10^{-6} feet	microns
drawn brass or copper	5	1.5
commercial steel	150	45
wrought iron	150	45
asphalted cast iron	400	120
galvanized iron	500	150
cast iron	850	260
wood stave	600 - 3000	200 - 900
concrete	1000 - 10,000	300 - 3000
riveted steel	3000 - 30,000	900 - 9000

Pipe Roughness for use with Darcy Weisbach Equation

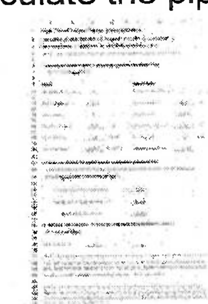
The calculations in this example spreadsheet proceed in three steps, after the needed data has been input. The first step is calculating the friction factor, f, using the equation for 'completely turbulent flow,' $f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}$. The second step is an iterative calculation with the more general equation for friction factor: $f = \{-2\log_{10}[((\varepsilon/D)/3.7) + (2.51/(Re^*(f^{1/2})))]\}^{-2}$, which gives f as a function of both ε/D and Reynolds number, to zero in on a better estimate for f. The third step, calculating frictional head loss and frictional pressure drop is quite straightforward after the value of f is determined.

The example spreadsheet in the image uses U.S. units, but both U.S. and S.I. versions can be downloaded below.

Click here to download this Excel template in U.S. units.

Click here to download this Excel template in S.I. units.

Calculation of Required Pipe Diameter



The Excel spreadsheet template shown in this section will calculate the pipe diameter needed to carry a specified flow rate of fluid with known density and viscosity, with a specified maximum head loss. The same iterative procedure is used to calculate the friction factor, f, however an assumed value of pipe diameter, D, is needed to start the process, because a value for D is needed to determine a value for f. After a value for f is found using the assumed D, then

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	0.529	cfs	Ave. Velocity, **V** =	6.1	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	192,328	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0170
Repeat calc of f using new value of f:	f =	0.0159
Repeat again if necessary:	f =	0.0158

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$$(h_L = f(L/D)(V^2/2g) \quad \text{and} \quad \Delta P_f = \rho g h_L)$$

Frictional Head Loss, h_L	245.5	ft
Frictional Pressure Drop, ΔP_f	15291	psf
Frictional Pressure Drop, ΔP_f	106.19	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2 \log_{10}(D/\varepsilon)^{-2}]$

Inputs			Calculations		
Pipe Diameter, D =	4	in	Pipe Diameter, D =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, f =	0.00805	
Pipe Length, L =	9052	ft	Cross-Sect. Area, A =	0.0873	ft^2
Pipe Flow Rate, Q =	0.955	cfs	Ave. Velocity, V =	10.9	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, Re =	347,208	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

= 1.041 oz/fl oz
= .9977 g/cc

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0150
Repeat calc of f using new value of f:	f =	0.0141
Repeat again if necessary:	f =	0.0142

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$$(h_L = f(L/D)(V^2/2g) \quad \text{and} \quad \Delta P_f = \rho g h_L)$$

Frictional Head Loss, h_L	717.4	ft
Frictional Pressure Drop, ΔP_f	44684	psf
Frictional Pressure Drop, ΔP_f	310.30	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow **$[f = 1.14 + 2 \log_{10}(D/\varepsilon)^{-2}]$**

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	0.487	cfs	Ave. Velocity, **V** =	5.6	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	177,058	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0174
Repeat calc of f using new value of f:	f =	0.0160
Repeat again if necessary:	f =	0.0161

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$(h_L = f(L/D)(V^2/2g)$ and $\Delta P_f = \rho g h_L)$

Frictional Head Loss, h_L	211.7	ft
Frictional Pressure Drop, ΔP_f	13182	psf
Frictional Pressure Drop, ΔP_f	91.54	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,

for given flow rate, Q, pipe diam., D, pipe length, L,

pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	1.067	cfs	Ave. Velocity, **V** =	12.2	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	387,927	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2^*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re^*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0147
Repeat calc of f using new value of f:	f =	0.0139
Repeat again if necessary:	f =	0.0139

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$$(h_L = f(L/D)(V^2/2g) \quad \text{and} \quad \Delta P_f = \rho g h_L)$$

Frictional Head Loss, h_L	877.5	ft
Frictional Pressure Drop, ΔP_f	54651	psf
Frictional Pressure Drop, ΔP_f	379.52	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,

for given flow rate, Q, pipe diam., D, pipe length, L,

pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, f =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	1.638	cfs	Ave. Velocity, **V** =	18.8	ft/sec
Fluid Density, ρ =	1.936	slugs/ft^3	Reynolds number, **Re** =	595,525	
Fluid Viscosity, μ =	2.034E-05	lb-sec/ft^2			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0135
Repeat calc of f using new value of f:	f =	0.0128
Repeat again if necessary:	f =	0.0129

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$(h_L = f(L/D)(V^2/2g)$ and $\Delta P_f = \rho g h_L)$

Frictional Head Loss, h_L	1921.4	ft
Frictional Pressure Drop, ΔP_f	119664	psf
Frictional Pressure Drop, ΔP_f	831.00	psi

Water - Dynamic and Kinematic Viscosity

Viscosity of water at temperatures between *0 - 100°C (32 - 212°F)* - in Imperial and SI Units

Home
• Acoustics
• Air Psychrometrics
• Basics
• Combustion
• Drawing Tools
• Dynamics
• Economics
• Electrical
• Environment
• Fluid Mechanics
• Gas and Compressed Air
• HVAC Systems
• Hydraulics and Pneumatics
• Insulation
• Material Properties
• Mathematics
• Mechanics
• Miscellaneous
• Physiology
• Piping Systems
• Process Control
• Pumps
• Standards Organizations
• Steam and Condensate
• Thermodynamics
• Water Systems

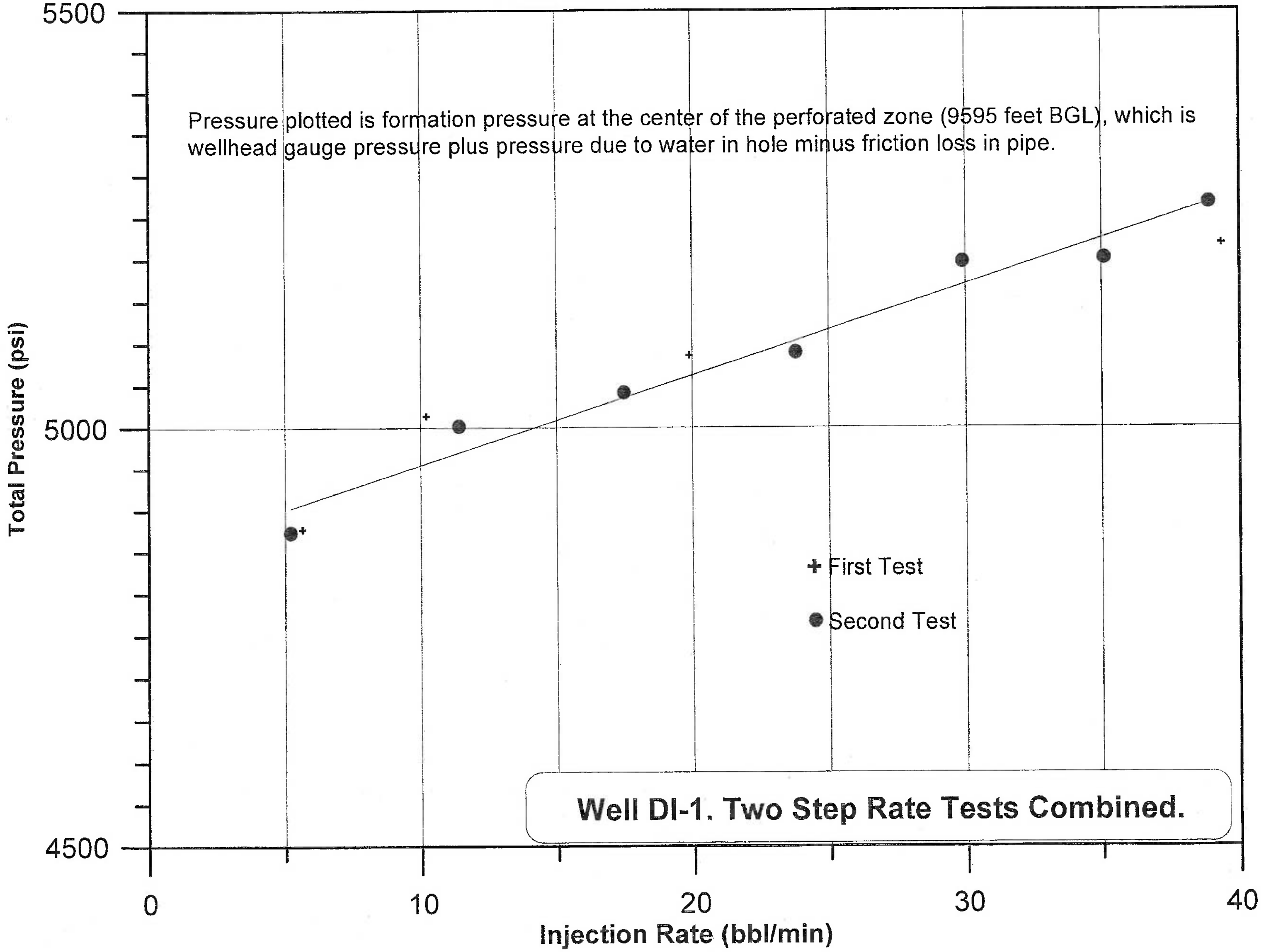
Dynamic and Kinematic Viscosity of Water in Imperial Units (BG units):

Temperature - *t* - (°F)	Dynamic Viscosity - *μ* - (lb s/ft²) x 10⁻⁵	Kinematic Viscosity - *ν* - (ft²/s) x 10⁻⁵
32	3.732	1.924
40	3.228	1.664
50	2.730	1.407
60	2.344	1.210
70	2.034	1.052
80	1.791	0.926
90	1.580	0.823
100	1.423	0.738
120	1.164	0.607
140	0.974	0.511
160	0.832	0.439
180	0.721	0.383
200	0.634	0.339
212	0.589	0.317

Dynamic and Kinematic Viscosity of Water in SI Units:

Temperature - *t* - (°C)	Dynamic Viscosity - *μ* - (N s/m²) x 10⁻³	Kinematic Viscosity - *ν* - (m²/s) x 10⁻⁶
0	1.787	1.787
5	1.519	1.519
10	1.307	1.307
20	1.002	1.004
30	0.798	0.801
40	0.653	0.658
50	0.547	0.553
60	0.467	0.475
70	0.404	0.413
80	0.355	0.365
90	0.315	0.326
100	0.282	0.294

- *$1\ N\ s/m^2 = 1\ Pa\ s = 10$ poise = 1,000 milliPa s*
- *$1\ m^2/s = 1 \times 10^4\ cm^2/s = 1 \times 10^4$ stokes = 1×10^6 centistokes*
- Kinematic viscosity converter


5500
5000
4500
Total Pressure (psi)
0
10
20
30
40
Injection Rate (bbl/min)
Pressure plotted is formation pressure at the center of the perforated zone (9595 feet BGL), which is wellhead gauge pressure plus pressure due to water in hole minus friction loss in pipe.
First Test
Second Test
Well DI-1. Two Step Rate Tests Combined.

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			Calculations		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	2.230	cfs	Ave. Velocity, **V** =	25.6	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	810,757	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2^*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re^*(f^{1/2})))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0127
Repeat calc of f using new value of f:	f =	0.0122
Repeat again if necessary:	f =	0.0123

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$(h_L = f(L/D)(V^2/2g)$ **and** $\Delta P_f = \rho g h_L)$

Frictional Head Loss, h_L	3383.4	ft
Frictional Pressure Drop, ΔP_f	210719	psf
Frictional Pressure Drop, ΔP_f	1463.33	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,
for given flow rate, Q, pipe diam., D, pipe length, L,
pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	2.800	cfs	Ave. Velocity, **V** =	32.1	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	1,017,991	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0122
Repeat calc of f using new value of f:	f =	0.0118
Repeat again if necessary:	f =	0.0118

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$$(h_L = f(L/D)(V^2/2g) \quad \text{and} \quad \Delta P_f = \rho g h_L)$$

Frictional Head Loss, h_L	5143.5	ft
Frictional Pressure Drop, ΔP_f	320343	psf
Frictional Pressure Drop, ΔP_f	2224.60	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,

for given flow rate, Q, pipe diam., D, pipe length, L,

pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			Calculations		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, **f** =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	3.290	cfs	Ave. Velocity, **V** =	37.7	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	1,196,139	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re*(f^{1/2})))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0119
Repeat calc of f using new value of f:	f =	0.0115
Repeat again if necessary:	f =	0.0115

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$(h_L = f(L/D)(V^2/2g)$ and $\Delta P_f = \rho g h_L)$

Frictional Head Loss, h_L	6927.8	ft
Frictional Pressure Drop, ΔP_f	431470	psf
Frictional Pressure Drop, ΔP_f	2996.32	psi

Pipe Flow/Friction Factor Calculations I: (U.S. units)

Calculation of Head Loss, h_L, or Frictional Pressure Drop, ΔP_f,

for given flow rate, Q, pipe diam., D, pipe length, L,

pipe roughness, ε, and fluid properties, ρ & μ.

1. Determine Friction Factor, f, assuming completely turbulent flow $[f = 1.14 + 2\log_{10}(D/\varepsilon)^{-2}]$

Inputs			**Calculations**		
Pipe Diameter, **D** =	4	in	Pipe Diameter, **D** =	0.3333	ft
Pipe Roughness, ε =	0.0000033	ft	Friction Factor, f =	0.00805	
Pipe Length, **L** =	9052	ft	Cross-Sect. Area, **A** =	0.0873	ft^2
Pipe Flow Rate, **Q** =	3.640	cfs	Ave. Velocity, **V** =	41.7	ft/sec
Fluid Density, ρ =	1.936	$slugs/ft^3$	Reynolds number, **Re** =	1,323,388	
Fluid Viscosity, μ =	2.034E-05	$lb\text{-}sec/ft^2$			

2. Check on whether the given flow is "completely turbulent flow"

(Calculate f with the transition region equation and see if differs from the one calculated above.)

$$f = \{-2^*\log_{10}[((\varepsilon/D)/3.7)+(2.51/(Re^*(f^{1/2}))]\}^{-2}$$

Transition Region Friction Factor, f:	f =	0.0117
Repeat calc of f using new value of f:	f =	0.0114
Repeat again if necessary:	f =	0.0114

3. Calculate h_L and ΔP_f, using the final value for f calculated in step 2

$$(h_L = f(L/D)(V^2/2g) \quad \text{and} \quad \Delta P_f = \rho g h_L)$$

Frictional Head Loss, h_L	8347.8	ft
Frictional Pressure Drop, ΔP_f	519912	psf
Frictional Pressure Drop, ΔP_f	3610.50	psi